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# ADHESIVENESS OF POWDERS, AND ITS APPLICATION IN THE DETERMINATION OF GRAIN SIZE

by

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No 1, pp 10-11.

The adhesion of powders to a solid base is determined, in addition to the grain size, also by a constant which is characteristic of the material.

* * *

A plate covered with powder may be inclined up to a given angle when the powder slides off by itself, as a whole, and all at once. Fig.1 shows the force parallelogram where at the moment of sliding off,

$$K = L \qquad (1)$$

On the basis of the classical Coulomb theory of adhesive friction L is equal to the frictional force R, and

$$R = \mu \cdot N = \mu \cdot m \cdot g \cdot \cos \varphi \qquad (2)$$

(where $\mu$ = coefficient of friction, g = acceleration due to gravity, m = mass of powder). As can be seen from the figure,

$$K = m \cdot g \cdot \sin \varphi \qquad (3)$$

thus we get from (1), (2) and (3):

$$m \cdot g \cdot \sin \varphi = \mu \cdot m \cdot g \cdot \cos \varphi \qquad (4)$$

and from this,

$$\mu = \tan \varphi \qquad (5)$$

When m is varied by changing the thickness of the powder layer on the plate, there is obtained for m . g . cos $\varphi$ and m . g . sin $\varphi$ a whole series of values which, when plotted against each other, give a straight line passing through the origin and having a slope $\mu$ .(1)

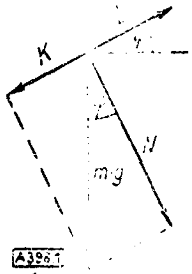


Fig.1

Fig.2 shows such a series of measurements for dolomite powder of relatively large grain size in which, as is seen, conditions (4) and (5) are satisfied.

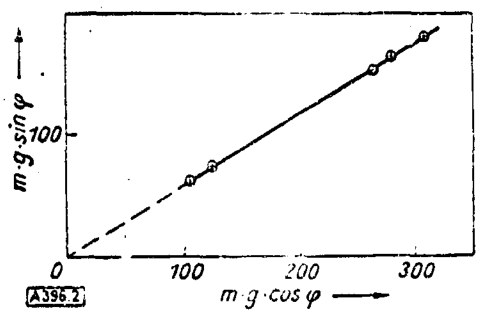


Fig.2
Dolomite Powder, 400 to 500 . $10^{-4}$ cm

In the case of fine-grain material, however, the behavior is represented by Fig.3. The values again lie on a straight line which, however, does not pass through the origin but intersects the ordinate at a given height H. Hence, in this case, instead of Eq.(4), we must write:

$$m \cdot g \cdot \sin\varphi = \mu \cdot m \cdot g \cdot \cos\varphi + H \qquad (6)$$

or

$$L = R + H.$$

(1) Cf. F. Conrad, E. Cremer and T.Kraus, Radex Rundschau (Radex Review) 1951 (in press), as well as the discussion of adhesive friction in H. Donandt, Z.Ver.Dtsch.Ing. 80, 821 (1936) and the literature cited therein.

... there arises, in addition to the friction, also an adhesive force. H.

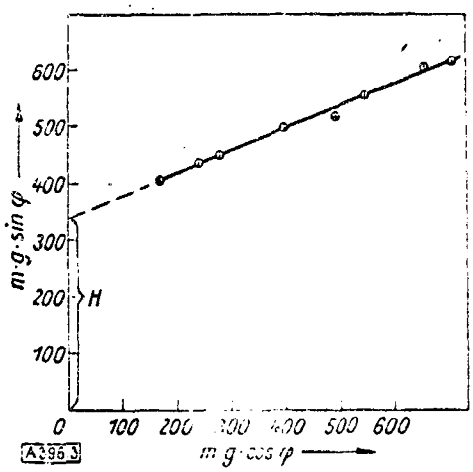


Fig. 3.
Dolomite Powder, 75 to 88 . $10^{-4}$ cm

In the case of a sufficiently small amount of powder the angle of inclination rises above 90°. The limiting value of m at which the powder just slips off at 90° is calculated from (6) by substituting 90° for $\varphi$ :

$$m = H / g \qquad (7)$$

In this way the significance of H becomes very clear: H is a measure of the maximum amount (m) which may adhere to the plate when the latter is rotated by 90°, without falling off.

The adhesive force is inversely proportional to the grain diameter d (cf. last column of the Table). Further, H is proportional to surface area F, so that

$$H = h \cdot (F/d) \qquad (8)$$

where h, whose dimension is that of surface tension (dyn/cm), is denoted as adhesive stress.

The adhesive force H defined according to (8) also contains F, an instrument constant. This may be avoided when total mass m of the powder is replaced by mass $m_K$, the average mass of a grain in contact with the surface. Then,

$$m_K = (m \cdot d^2)/F,$$

and Eq. (6) acquires the form:

$$m_K \cdot g \cdot \sin\varphi = \mu \cdot m_K \cdot g \cdot \cos\varphi + H_K.$$

The corresponding adhesive force for one grain is then:

$$H_K = \text{[illegible]}$$

which no longer contains the term F. We have, however, preferred the first formulation since it contains only the two values m and $\varphi$ measured directly in the experiment.

Using dolomite powders having grain sizes 75-88 $.10^{-4}$ cm and 150-200 $. 10^{-4}$ cm grain diameter, the value of the adhesive stress obtained was 0.99. The following table gives a resume of the results obtained with magnesite powders, decomposed magnesite as well as iron- and molybdenum powder:

| Material | d 2 Korngröße [1] $10^{-4}$ cm | Unterlage 3 | H 4 Haftkraft [dyn] | H[2]) F | h = Haftspannung 5 | H·d |
|---|---|---|---|---|---|---|
| Magnesit | 200—300 | Glas (2,84) 6 | 110 | 39 | 0,97 | 2,8 |
| | 150—200 | ,, | 160 | 56 | 0,99 | 2,8 |
| | 88—150 | ,, | 235 | 83 | 0,99 | 2,8 |
| | 75— 88 | ,, | 330 | 116 | 0,95 | 2,7 |
| | 60— 75 | ,, | 450 | 169 | 1,14 | 3,2 |
| | 200—300 | Magnesit (3,48 [2]) | 100 | 29 | 0,72 | 2,5 |
| | 150—200 | ,, | 140 | 40 | 0,70 | 2,5 |
| | 88—150 | ,, | 210 | 60 | 0,72 | 2,5 |
| | 75— 88 | ,, | 310 | 89 | 0,72 | 2,5 |
| | 60— 75 | ,, | 360 | 103 | 0,70 | 2,4 |
| | 200—300 | Nickel (3,85) | 105 | 27 | 0,69 | 2,6 |
| | 150—200 | ,, | 150 | 39 | 0,69 | 2,6 |
| | 88—150 | ,, | 220 | 57 | 0,68 | 2,6 |
| | 75— 88 | ,, | 320 | 84 | 0,68 | 2,6 |
| | 60— 75 | ,, | 390 | 102 | 0,69 | 2,6 |
| 7 Abgebauter Magnesit, Abbautemperatur 500° C | | | | | | |
| | 150—200 | Glas (2,84) | 40 | 14 | 0,25 | 0,7 |
| | 60— 75 | ,, | 105 | 37 | 0,25 | 0,7 |
| 1 | | Abbautemperatur 800° C | | | | |
| | 150—200 | Glas (2,84) | 55 | 19 | 0,34 | 1,0 |
| | 60— 75 | ,, | 140 | 49 | 0,33 | 1,0 |
| 8 Hametag-Eisenpulver | | | | | | |
| | 100—150 | Glas (2,84) | >10 | — | — | — |
| | 60—100 | ,, | 80 | 26 | 0,23 | 0,6 |
| | <60 | ,, | 290 | 102 | — | — |
| | 150—200 | Nickel (3,85) | 15 | 4 | 0,07 | 0,2 |
| | 100—150 | ,, | 20 | 5 | 0,06 | 0,2 |
| | 60—100 | ,, | 30 | 8 | 0,06 | 0,2 |
| | <60 | ,, | 110 | 29 | — | — |
| 9 Molybdän-Pulver | | | | | | |
| | 11 | 10 Molybdän ([illegible]) | 1400 | 350 | 0,38 | 1,5 |
| | 2,5 | ,, | 6100 | 1525 | 0,38 | 1,5 |

Table 1

1) Decomposition Temperature 2) Grain Size 3) Support 4) Adhesive Force 5) Adhesive Stress 6) Glass 7) Decomposed Magnesite, Decomposition Temperature 500°C. 8) Hametag Iron Powder 9) Molybdenum Powder 10) Molybdenum

[For footnotes 2) and 3) in Table, see next page].

Because of the dependence of the adhesive force on particle diameter, shown in the last column of the table, it is possible to determine the particle diameter of a powder from the adhesive force, when the adhesive stress is known.

In the case of a mixture of two powders of which one behaves in accordance with Coulomb's theorem of friction (Fig.2) (= non-adhesive powder), and the other possesses an adhesive force (= adhesive powder), the adhesive force resulting upon mixture is shown in Fig.4; this adhesive force is very close to that calculated from the percentual composition of the adhesive powder. In this case one can determine only an upper limit for the particle diameter of the adhesive powder.

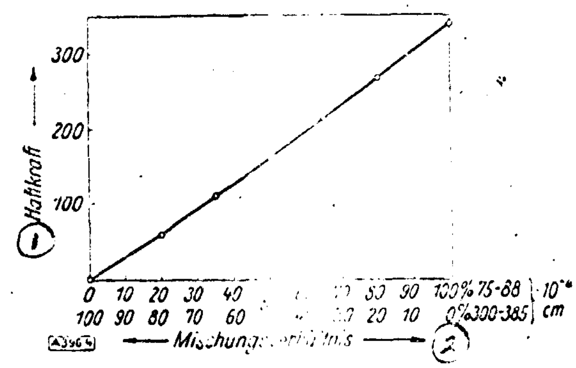


Fig.4. Adhesive Force in the Case of Mixtures of Adhesive and Non-Adhesive Dolomite Powder. 1) Adhesive Force
2) Composition of Mixture

The behavior of a mixture of two adhesive powders is different. Here the measured adhesive force agrees with that calculated after Eq.(8) within the accuracy of measurement (for d in this case we use the average grain diameter calculated according to the rule of mixtures)(Fig.5). This agreement is of great practical significance, since the powders encountered in practice are almost never of uniform particle size. Independently of the distribution function present, one obtains from the adhesive force the true average particle diameter. In the case of powders containing very fine portions (grain diameter a few $\mu$ ) it may happen that the coarser grains are to a certain extent "frosted" with a very tightly adhering layer of very fine particles. In this case the adhesive

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(2) Since the size of the individually used slide surfaces were different, we also entered in the Table the value H/F (adhesive force per unit surface) so as to obtain comparative H values.

(3) The base used was a compressed magnesite briquet $<60 \cdot 10^{-4}$ cm. Compression pressure was 6,000 kg/cm$^2$.

force gives the grain size of th... particle, since it is those that are in contact with the base and ... decisive for the adhesiveness.

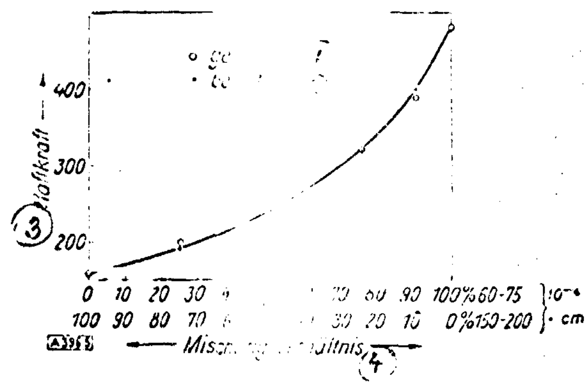

Fig.5. Adhesive Force in the Case of Mixtures of Two Adhesive Magnesite Powders. 1) Measured 2) Calculated 3) Adhesive Force 4) Composition of Mixture

## Experimental

The powder layer should at all points be equally thick and ... surface as even as possible. This is best accomplished by means of a uniform application of powder through a sieve (powder layers which are evened e.g. by pressing with a flat object, do not adhere). By application of layers of different thickness ... may be readily varied and subsequently determined accurately ... ighing in a small weighing dish. The corresponding sliding angle ... read off by means of a protractor. Between individual measurements ... oundation support is cleaned as well as possible in a dry manner (fo... mple, brushing). Changes in atmospheric humidity may bring about ... tuations in the measured values of H, but apart from extreme humidi... evels these fluctuations are, according to our experiments per... d so far, never so great as to lead to substantial errors in the determination of grain size.

## Summary

The adhesion of a powder is brought about, in addition to friction, also by an adhesive force H which is inversely proportional to grain diameter. The proportionality factor h is a material constant characteristic of a given powder/foundation system, and has the dimension of surface tension. When h is known, the average grain diameter of powders of unknown grain size may be determined by adhesion measurements.